Public Interest Energy Research (PIER) Program FINAL PROJECT REPORT

UNI-SOLAR: LAMINATE AND BATTEN PHOTOVOLTAICS ROOFING SYSTEM

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Uni-Solar: Laminate and Batten Photovoltaics Roofing System is the final report for the Laminate & Batten System project (Contract Number 500-00-034), conducted by United Solar Ovonics. The information from this report contributes to PIER's Renewable Energy Technologies program.

For more information on the PIER Program, please visit the Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

The overall goal of this project was to develop a simple, low cost, and quick-to-install building integrated photovoltaic (PV) roofing system. Uni-Solar used its triple-junction thin-film amorphous product to develop a PV roofing system which can be applied to any new or existing roof that has a plywood deck, particle board deck, or any other type of solid, continuous under-structure. The resulting product is an attractive, low-profile PV Roof which blends well with a composite shingle roof and is a true building integrated PV system.

This project final report describes the development of the simple, low cost, batten system for installing PV laminates on a wood deck. Improvements include a Class A fire rating and an Underwriters Laboratory Inc® (UL) listing as a roofing system. The project reduced shipping and installation costs by more than 50%. Installation time was reduced by adding self-adhesive protective covering to laminates and quick disconnects. The development of ridge cap and head flashing strategies, and End-to-End termination of laminates helped Uni-Solar overcome architectural challenges.

The project included five demonstration/field trial roofs in three states, demonstrating a final PV Roof product installed cost of \$7.23/watt.

Keywords: Uni-Solar, solar, photovoltaic, building-integrated PV, BIPV, electricity production, distributed generation, laminate, batten system, PV roofing

Executive Summary

Introduction

United Solar Ovonics (Uni-Solar) has completed its PIER research and development project "Laminate and Batten PV Roofing System." The goal was to develop an inexpensive and easy-to-install building integrated photovoltaic roofing system which could be applied to any new or existing roof with a solid, continuous under-structure. No comparable product existed at the outset of this project. The resulting roofing system is based on Uni-Solar's triple-junction thin-film amorphous silicon photovoltaic (PV) product.

Objectives

This program addresses two PIER Program Renewable Energy objectives:

- 1. Provide California with more diversified energy sources through the use of renewable energy technology.
- 2. Reduce environmental risks from California's electric system by developing a renewable energy source which does not emit nitrous oxides, sulfur oxides, and carbon dioxide when generating electricity.

Purpose

The goal was to develop an inexpensive, easy, and quick-to-install building integrated photovoltaic roofing system which can be applied to any new or existing roof that has a plywood deck, particle board deck, or any other type of solid, continuous understructure.

Project Objectives

Specific objectives of the project were to:

- 1. Create a low cost, dual function photovoltaic roofing system using Uni-Solar large area thin film technology.
- 2. Accommodate the widest range of residential and light commercial roofs.
- 3. Develop fast, easy installation methods.
- 4. Provide Class A fire rating and UL listing on all Uni-Solar building-integrated photovoltaic products
- 5. Use high profile demonstration projects to highlight the advantages of the new products.
- 6. Develop manuals, videos, and training program for designers, installers, and users.

Project Outcomes

Due to the considerable support by the California Energy Commission, which enabled this PIER project to emerge, United Solar Ovonics was able to realize the following key accomplishments during the development of the PV Roofing product:

- Developed a clamping batten system that is a weatherproof combination roofing and PV product. The batten system is made of commercially available components costing only 40 cents per Watt.
- Obtained a Class A fire rating for low slope applications and a UL listing for the Building Integrated Photovoltaic products developed in this project including these details:
 - o PV modules may be applied to any roof panel construction within the category TGKX (Roof Deck Constructions).
 - o "Flame spread" tests with Elk VersaShield underlayment produced Class A rating on a maximum slope of 2:12, and a Class B rating on a maximum slope of 3:12 and a Class C rating on unrestricted slope.
 - o The product is listed by Underwriters Laboratory as a roofing system in their 2003 Directory of Roofing Materials & Systems.
- Identified and completed tests to ensure PV Roofing product market readiness.
- Reduced shipping and installation costs by more than 50 percent by the following measures:
 - O Developing less expensive alternatives for shipping. The product is now delivered by UPS rolled up in small boxes. These boxes hold approximately 500 Watts of laminates and can be unloaded by hand without the need of a forklift. A huge improvement over shipping laminates adhered to bulky, heavy metal pans.
 - Adding self adhesive protective covering to laminates which are less labor intensive than paper and protects laminates from scuffing and electric shocks during installation.
 - o Installation time of 2 kW PV Roofing system was drastically reduced and can now be accomplished by two people in five to six hours, excluding the wiring of the inverter.
- Developed software, available on the website (www.uni-solar.com), that will
 assist salespeople as well as potential customers in determining expected
 performance output and cost information for specific projects.

- Completed Field Applied PV Roofing System Installation and Training Manual with step by step installation instructions.
- Installed five demonstration/field trial roofs in three states—Pennsylvania,
 Virginia, and California—providing important information on installation costs
 and procedures as well as system design costs and expected outputs. Highlights
 included:
 - The mock-ups and field trial installations resulted in the development of a clamping batten system that is a weatherproof, combination roofing and PV product.
 - Five field tests were demonstrated, sequentially increasing the evolution of to the final product and decreased the costs from \$16.74 per watt to a final PVR product installed cost of \$7.23 per watt.
 - Final installation on a residential roof was performed by a local PV installer using the improved insert molding Clamping Battens System. The result was a very attractive low-profile PV Roof which blends well with the composite shingle roof.
- Architectural challenges were overcome during the course of the project including:
 - Ridge cap and head flashing termination strategies evolved into elegant solutions with the use of quick connects, now easily protected under the ridge cap.
 - End-to-End termination of laminates was fully developed and initial designs on a laminating machine were completed.
- Expenses for designing and building a component production facility, including multiple project tasks, were eliminated because of the selection of commercially available components.

The installation in Sacramento, California, shown in Figure 1, is installed at SMUD's Hedge Substation and can be available for viewing by potential customers.



Figure 1. Laminate and batten PV Roofing system installed at SMUD's Hedge Substation

Photo courtesy of SMUD; Photo Credit: Uni-Solar

Conclusions, Recommendations, and Benefits to California

The result of this project is a commercially viable photovoltaic roofing solution that is inexpensive, fast and easy to install, and can be applied to almost any type of roof—new or existing. Benefits of the PV Roof include increased customer acceptance, lower cost, and fast, easy installation with optimum aesthetics. The PV Roof will blend in with the surrounding roof and add, rather than detract from, the overall appearance of the building.

Other benefits of the PV Roof include:

- Reduced installed prices for a PV Roofing system to \$7 to \$8/Watt.
- Increased customer acceptance due to better aesthetics.
- Improved access to electrical termination with ridge cap strategy.
- Eliminated roof penetrations.
- Allowed application on odd shaped roofs due to different length laminates.
- Attained listed by UL as a roofing system in the 2003 Directory of Roofing Materials & Systems.
- Achieved fast and easy installation (128 Watt module in less than 10 minutes).

1.0 Introduction

The purpose of this report is to document the research and development effort of Uni-Solar during the Laminate & Batten Roofing System Project. This report outlines the work completed from January 2002 through January 2004. This document reviews major accomplishments made during this period and presents conclusions, recommendations, and suggestions for future development work.

1.1 Background and Overview

United Solar Ovonics (Uni-Solar) manufactures a photovoltaic (PV) laminate utilizing proprietary triple junction thin-film amorphous silicon solar cells manufactured at a 30 MW continuous roll-to-roll production facility in Auburn Hills, Michigan. The laminates come with a bonding adhesive factory-installed on the back. For residential and light commercial roofs, these roofing laminates are typically bonded on 16-inch wide (min) flat Galvalume™ pans and installed as a standing-seam, sheet metal PV Roof. Bonding of the PV laminates is either done on the roof, at the building site, or at the factory. Although this creates a rugged and long-lasting roof, the cost of the metal roofing product, combined with the cost of shipping and installing the product can make this type of photovoltaic roofing more expensive than competing technologies.

The Project objective was to develop an inexpensive, easy, and quick way to install the Uni-Solar PV laminates as a building-integrated photovoltaic (BIPV) roofing system that could be applied to any new or existing roof with a plywood deck, particle board deck, or any other type of solid, continuous under-structure. No comparable product exists at this time.

The laminate and batten PV Roof was to be researched and developed using the following approach:

- Design and test necessary hardware.
- Research and develop a new packaging and product-delivery system.
- Acquire UL listing.
- Complete and monitor initial demonstration phase of five projects. (Other demonstration projects would also be developed but not monitored as part of this project.)
- Develop manuals, videos, and a contractor training program.
- Design and build equipment to produce the BIPV product for high volume production.

1.2 Project Scope and Objectives

Specific objectives of the project were to:

- 1. Create a low cost, dual function photovoltaic roofing system using Uni-Solar large area thin film technology.
- 2. Accommodate the widest range of residential and light commercial roofs.
- 3. Develop fast, easy installation methods.
- 4. Provide Class A fire rating and UL listing on all Uni-Solar BIPV products.
- 5. Use high profile demonstration projects to highlight the advantages of the new products.
- **6.** Develop manuals, videos, and training program for designers, installers, and users.

1.3 Report Organization

Section 2.0 describes the project's main tasks: reduced shipping and installation costs, hardware development, UL approval, Class A fire rating, training programs, field trials, equipment design, build and test prototype equipment, and high-volume production line. Project outcomes for each completed task are discussed in Section 3.0. Conclusions, commercialization potential, recommendations, and benefits to California are covered in Section 4.0.

2.0 Project Approach

This Project scope was established with the following eight tasks and multiple subtasks:

- 1. Conceptual design: This task included design of the clamping batten hardware, "module" electrical design, laminate size and border trim, electrical termination, testing, packaging, shipping, handling, installation, etc. The PV Roof system was designed to take advantage of the most appropriate places for wire terminations: under the ridge cap and in the eave soffit. Then multiple laminate lengths with non-active portions were proposed to allow more complete coverage of hips and valleys.
- 2. Hardware development and PVR installation kit development: This task included development of a packaging spool and roller to simplify and reduce the cost of shipping and installation and also included several revisions of hardware for the clamping batten system.
- 3. Acquisition of UL listing and a Class A fire rating.
- 4. Demonstration projects: Multiple demonstration projects (field trials) were performed to understand different roofing challenges. These installations were selected, monitored, and evaluated to provide feedback in order to prove the utility of the PV Roof system and allow for improvements to be made.
- 5. Installation Documentation: Installation and operation manuals and videos were developed for the PVR system as well as design software and a training program for installer, homeowners, or contractors.
- 6. Production documentation: Design documents and equipment was developed for all new components so that the Laminate and Batten PV Systems could be produced in high volume.
- 7. High volume production prototype: Equipment was prototyped for high volume production of new components.
- 8. High volume manufacturing: Equipment was built and high volume manufacturing begun.

These last two tasks (7 and 8) were found to be unnecessary during the project as the components designed in this project were already available commercially.

2.1 Reduce Shipping and Installation Costs

The goals of reducing shipping and installation costs consisted of the following specific tasks:

 Design and make a shipping spool that will reduce both shipping and installation cost.

- Design a ridge/eave roller that will simplify the installation process and reduce cost.
- Develop a protective covering that keeps the laminate clean and prevents damage during shipping and installation and provides protection from electric shock during installation.
- Reduce the cost of installation by replacing junction boxes with quick electrical connects.

The results from these tasks were compared to the cost of shipping and installation of the original Uni-Solar product, which at the time the project began was only available in factory-bonded to 24-gauge structural standing seam roofing panels.

2.2 Hardware Development and UL Approval

2.2.1 PVR Kit Hardware

The procedure of developing the PVR Kit hardware consisted of the following specific tasks:

- Develop field applied bottom termination or other appropriate electrical termination strategies.
- Develop a Clamping Batten System to seal lap joints between adjoining modules.
- Develop a jig to trim modules for the appropriate overlap width on 16" centers.
- Develop inexpensive non-active roll roofing.
- Develop a ridge/eave roller that will simplify the installation process and reduce costs.

The approach used was to complete design drawings, build mock-ups, and complete several field trial installations. The mock-ups and field trials were analyzed to determine the performance of the Clamping Batten System. It was realized during the course of this project that the PVR needed to perform, not just as a PV system, but also as a roofing material. Therefore, the scope of this task was expanded to include further development of the product as a result of the testing.

2.2.2 UL Listing

The following steps were taken to seek UL Listing:

- Develop mock-ups of several different clamping batten strategies.
- Select a test article for UL testing. The Clamping Batten System with overlapping edges was selected. The overlapping edges were sandwiched between two clamping strips and fasteners were applied through batten clips at 2 feet oncenter (o/c). Standard architectural battens were snapped over the batten slips and an 8-foot-long mock-up was delivered to the UL testing facility.
- Support the successful completion of the tests.

2.2.3 Test Plan for Product's Performance as a Roofing System

This task was added to the original task list upon the realization that, because the PVR System does not rely on roofing substrates, it needs to be tested as a full roofing solution, not just as a photovoltaic product. The procedure was to develop a list of roofing tests that will be performed to assure the PVR system's structural integrity and durability. Passing the tests will result in building industry and code officials' confidence in the PVR system.

The approach taken was to contact the Underwriters Laboratories Inc.® (UL). A Roof Covering Materials group was organized to request approval for the PVR system and discuss what testing would be required. A Test Plan was developed to test the PVR as a roofing system.

2.2.4 Completion of Roofing and Adhesive Tests

UL completed the tests required to list the PVR as a roofing system. In addition, adhesive testing was done at the Bekaert Technology Center (BTC) in Belgium. Cold weather testing was done at Skandia, Michigan. Results from field trials were also used to bring about improvements to the design.

2.2.5 Further Clamping Batten Development Based on Findings from Roofing Tests

The first three field trials showed a weakness in weather tightness and stability of the full overlap of the Clamping Batten System. The roofing test showed successful testing on improved adhesives.

The original four-piece Clamping Batten System (Rev. 1) with fully overlapping edges and MFM adhesive was revised to create an improved three-piece Clamping Batten System (Rev. 2) with partially overlapping edges adhered with new SIKA adhesive.

The first three field trials also revealed that the cost of manufacturing and shipping the Rev. 2 clamping batten system was high, because the components could only be hand fabricated by a metal roofing fabricator who had the appropriate equipment and experience. To resolve this problem, a new two-piece clamping batten system (Rev. 3) was researched that employs a commercially available insert molding.

2.2.6 Electrical Termination Strategies

It was necessary to development termination strategies to electrically connect laminates together to satisfy the need for covering odd shaped roof areas. The absence of longer laminates to cover roofs larger than 18 feet (the longest laminate length) from ridge to eave necessitated the development of mid-roof termination strategies. There were six above roof termination strategies identified and mock-ups were made based on connection to the second generation clamping batten covers.

2.3 Class A Fire Rating

2.3.1 Class A on Low Slope (less than 3:12 pitch) roofs

Membrane roofing manufacturers advised that Class A fire rating could be obtained for low pitch installations (less than 3:12) by using fire retardant substrates in a roofing system.

Research was conducted on fire retardant underlayments and several possibilities were identified: Dens-Deck, Versa Shield, Inspecta-Shield, Tech Shield, etc. The Versa Shield product was selected as the first choice for UL fire testing and development.

Uni-Solar conducted Class A flame spread on laminates with Versa Shield. Testing was carried out at a slope 0.5:12 (a typical slope used in flat roof constructions). Results indicated that Class A fire rating was within reach for low-slope applications so official rating tests were then conducted.

2.3.2 Feasibility Study on Obtaining Class A Fire Rating on Slopes Greater Than 2:12

To determine the feasibility of obtaining a Class A fire rating on slopes greater than 2:12, two goals were set:

- 1. Develop a transparent adhesive with Class A fire rating.
- 2. Research how other polymer based roofing products have secured Class A fire rating.

The approach taken to researching the Class A fire rating included the following contacts and steps:

- Contacted several University testing labs to help with research and testing to secure Class A fire rating.
- Contacted membrane roofing manufacturer to learn how they gain Class A rating of flammable material.
- Sent samples to DuPont to check on alternative adhesives.
- Identified insulating substrates that could act as a fire retardant that could act as a Class A fire system.

Bekaert Testing Center in Belgium approached development of a transparent adhesive by performing literature search and testing in their laboratory.

2.4 Documentation of Training Programs

The approach for training involved making improvements to the website: www.uni-solar.com. A software package to assist potential customers as well as salespeople in estimating solar system cost and sizing was created and made accessible through the website. Additionally, an Owner's Manual and Installation Guide was completed.

2.5 Demonstrations and Field Trials

Criteria were created for selecting demonstration sites which could show Uni-Solar's superior performance in high heat, low light, and snow shedding conditions. See Section 3.5 for more detailed information on the field trial installations.

2.5.1 First Demonstration Installation—Chanticlear, Pennsylvania

The goal of the first field trial (1.28 kW system) was to test the PVR Kit in a real world installation over an existing shingle roof using untrimmed PVL laminates and currently available junction boxes. This installation would provide a benchmark for labor and material costs because this installation used currently available laminates and junction boxes, as well as adhesive, packaging, and paper protective coating. This will also allow for a cost comparison in future field trials where quick connects, new adhesive, shipping spool, and protective coatings will be utilized.

The following technical elements were also included as part of the goal of this field trial:

- Testing whether the laminates would properly adhere to the underlayment.
- Test if there would be enough pressure applied between the clamping strips to create a waterproof connection.
- Test the accuracy of the information and procedures in the Uni-Solar SmartRoof Solar Roofing Kit Utilizing Clamping Batten System Owner's Manual and Installation Guide of April 2002 (PVR Kit Manual).

2.5.2 Second Demonstration Installation—Franklin Park, Virginia

The second field trial (1.9 kW system) location chosen was Franklin Park in Virginia to quantify improvements to the hardware and the process.

2.5.3 Third Demonstration Installation—Eureka, California

The third field trial (2.55 kW system) location chosen was the Californians for Alternatives to Toxics (CAT) headquarters in Eureka, California, to test the full roof solution.

2.5.4 Fourth Demonstration Installation—Sacramento, California

The fourth field trial (1.9 kW system) was installed on a shed at SMUD's Hedge Substation in Sacramento, California. The goal of this field trial was to demonstrate the final version of the Clamping Batten PV Roofing system on a shed at SMUD's demonstration site. The following technical elements were evaluated as part of the task:

- 1. The amount of time and material saved by using the Insert Molding Clamping Batten System.
- 2. The adhesion of the PVR laminates to the VersaShield underlayment.
- 3. Any difficulty in installing the Z-closure within the new allowable penetration areas.

4. How working with local solar installers who are used to working with framed modules affects the installation process.

The approach taken was to contact the solar installation contractor in advance of this installation and provide the company with a task and materials list. The solar installer secured the materials and prepared the roof so that 22 PVR 87 laminates (87 Watt, 12 feet, 6.25 inches long by 16.75 inches wide modules) could be accommodated.

2.5.5 Fifth Demonstration Installation—Orangevale, California

A fifth field trial was completed after the end of the project to test the aesthetics and practical experience of a commercial installation on a residential newly constructed building. The approach taken was to contract with a solar installation contractor who installed a 1.74 kW PV system on a section of roof left bare by the homeowner. The installation was completed at the end of 2004 using match share provided by SMUD.

2.6 Equipment Design

2.6.1 Design Documents for Equipment to Produce Shipping and Installation Tools

The goal of this task was to examine completed design documents for equipment to produce the shipping and installation tools. If equipment needed to be designed, this would have been performed; however, it was not found to be necessary.

2.6.2 Design Documents for Equipment to Produce the Clamping Batten System

The goal of this task was to determine what equipment was needed to produce Clamping Batten System components. If equipment needed to be designed, this would have been performed; however, it was not found to be necessary.

2.7 Build and Test Prototype Equipment

The goal of this task was to build and test necessary equipment for producing PVR roofing; however, no equipment was found to be necessary since the final design made use of commercially available components, so this task was not needed.

2.8 High Volume Production Line

The original intention of Uni-Solar was to develop a manufacturing facility in California during this project. While still looking at California manufacturing opportunities, it was determined more prudent to delete this task from the project and allow the market to determine the best time for a new manufacturing facility.

3.0 Project Outcomes

This section of the report describes the results and outcomes for each task and subtask in the project.

3.1 Reduce Shipping and Installation Costs

The premise behind reducing shipping costs was the shift from factory bonding to site bonding of the laminates. The original site-bonded photovoltaic laminate (PVL), which comes in a flexible sheet approximately 15 1/2-inch wide and from 4 to 18 feet long, is now delivered by UPS rolled up in small boxes. These boxes hold approximately 500 Watts of laminates and can be unloaded by hand without the need of a forklift. The laminates are then bonded on site to metal roofing pans. The cost of shipping the laminates was reduced to less than \$0.10/Watt resulting in a savings of \$1.90 to \$3.90/Watt. The added cost of bonding the laminates to the roof on-site is estimated at between \$0.20 and \$0.60/Watt, but with the introduction of the PVR system (laminates are 17 inches wide and from 4 to 18 feet long), bonding will occur directly on the roof and take no more time than installing a metal roofing pan. The overall savings in shipping and installation is between \$1.15 and \$2.65/Watt.

Four major advancements were made to reduce shipping and installation costs:

- Shipping Spool
- Ridge Roller
- Protective Coatings
- Quick Electrical Connects

3.1.1 Shipping Spool

The goal was to design a shipping spool to reduce both shipping and installation costs.

The first step was to develop a laminate shipping spool that is also used during installation to easily unroll the laminate on the roof. The 17-pound shipping spool that was developed is pictured in Figure 2. Each spool holds approximately 0.5kW of PV and mounts on the specially designed ridge roller. A fully loaded shipping spool weighs 75-85 pounds.

Components	Cost
½ sheet of ½" plywood	\$5.00
1 ½' x 1' diameter Sonotube	\$1.50
$4-\frac{1}{4}$ " diameter x 18 bolts	\$2.00
Nuts, washers, screws	<u>\$0.50</u>

Total labor \$9.00 plus 1 hour

Note: Quantity purchases may cut price in half.

The shipping cost from California to Michigan in the original box is \$250 to \$500.

UPS rate for new shipping spool from California to Michigan is \$33.

A prototype was built to demonstrate the final design with the following configuration:

- Dimensions w/ wheels: 24"x32"x36" high
- Weight w/o spool: 53 lbs
- Materials used: 2-22" diameter ½" plywood, 4-1/4" all thread, nuts and washers
- 18" length of Sono tube
- Overall dimensions: 22" diameter x 19" high
- Empty spool weight: 17 lbs
- Loaded spool: 500 Watts of laminates weighing from 75-85 lbs.



Figure 2. Shipping spool Photo Credit: Uni-Solar

The result was a 22" diameter x 19" high shipping spool that can hold 500 Watts of laminates and weighs between 75-85 pounds. The shipping spool has a recessed area in the top that will protect the shipping label and installation manual, and the bottom wooden panel unscrews to reveal storage for electrical j-boxes and adhesives.

Advantages and features of the new roofing spool include:

- Current large and heavy shipping box delivery time is unpredictable, approximately one to two weeks; is hard to track, and requires large flat-bed trucks.
- The shipping spool can be shipped UPS overnight or second day, is easy to track, and smaller trucks can deliver anywhere.
- Spools are reusable and made of reusable materials that don't have to enter the waste stream.
- Fully loaded spools (including adhesives and electrical components) will weigh around 100 lbs. Spools can be unloaded by one person, as well as easily rolled around a building site by one person. As an alternate method, two people using a pipe through the center of the spool can carry it.
- The spool offers uniform, even support for the PV module material to prevent kinking during transport and installation.
- The spool can also be used to ship 100 feet to 300 feet of clamping batten roofing.

3.1.2 Ridge Roller

The second step in reducing shipping and installation costs was to develop a spool reel stand that eliminated the need to lift laminates from their shipping box and hand-carry them to the bonding site. This process often resulted in kinking, bending, or otherwise damaging the laminates. This spool reel stand could roll along the ridge of the roof and easily dispense the laminates without the possibility of bending or kinking. The resulting ridge roller was developed in a self-contained box that holds one spool of laminate. The ridge roller weights 56 pounds and can be shipped via UPS. The cost savings stems from not having to replace damaged laminates and in reduced installation time.

The ridge roller rolls parallel to the ridge at the uppermost portion of the roof. Spools are loaded into the ridge roller and the laminates are pulled off the spool one at a time and aligned with the edge of the clamping strip. There are from 4 to 16 laminates on each spool, depending on the length of the laminate. Empty spools are replaced with new ones by pulling them out of and sliding them back into a slot in the ridge roller. Only one ridge roller is needed per installation and requires a deposit that will be refunded when it is returned to the factory. The factory will take the spools back and reimburse shipping costs.

To verify functionality and cost effectiveness of the design, a prototype ridge eave roller was built. Although the spool and ridge eave roller proved to be functional, a lower cost method of shipping and installation was ultimately adopted by Uni-Solar. The shipping department packed laminates in a shipping box approximately 4-foot square and 17 inches high. This protected the laminates well and the box could be moved with a pallet jack or forklift. Once the box was at the building site, individual laminates were removed one at a time and carried to the rooftop for installation.



Figure 3. Ridge roller Photo Credit: Uni-Solar

Materials used: $\sin 2'x2'$ ½" plywood boards, eight fasting screws w/wing nuts, four 8-inch diameter rubber wheels that can be stored in the box w/ full spool. Overall dimensions w/o wheels: 2-foot cube.

3.1.3 Protective Coating

A protective covering was developed to keep the laminates clean and prevent damage during shipping and installation. It also provided protection from electric shock during installation by blocking sunlight from the laminates.

The third step in reducing shipping and installation costs was to improve the manner in which the laminates were protected during shipping. Initially the laminates were individually wrapped in paper that was held together with masking tape. The paper was problematic in that you had to unroll the laminate fully on the ground before bonding could take place. In addition, the paper stuck to the adhesive edges of the laminates and had to be tediously removed. This whole process took anywhere from 5 to 10 minutes depending on the length of the laminate. Because the paper was unwrapped before installation, the laminate was totally unprotected during installation and subjected to scuffing and other damage. At best, this process required a thorough cleaning of the laminates when the installation was completed and at worst, some laminates had to be replaced due to damage from installation-incurred surface cuts.

The solution to these problems was to utilize a thin film protective coating, similar to that used on metal roofing pans to prevent scratches during shipping. This 14 1/2-inch wide protective coating only covers the active portion of the laminate, leaving approximately 1 1/2 inches on either edge exposed, so that there is no problem with the coating sticking to the edges when it is time to remove it. An added benefit is that it also protects the laminate during installation. The coating comes in either clear or opaque. The clear coating allows testing of the laminates before they are installed, and the opaque coating blocks sunlight and eliminates the possibility of electric shock during installation. Upon completion of the installation the protective coating is removed to reveal clean, scratch free laminates. Shipping costs are reduced because the factory

machine-applied protective coating eliminates the need for laborers to wrap the paper by hand and secure it with tape.



Figure 4. Protective coating on one-cell samples

Top sample: 5 mil, 14.5" wide opaque protective coating Middle sample: 3 mil, 14.5" wide clear protective coating Lower sample: no protective coating on 15.5"wide laminate Photo Credit: Uni-Solar

Uni-Solar implemented the use of 5 mil, 14.5" wide opaque protective covering and 3 mil, 14.5" wide clear protective coating that keeps the laminate clean and prevents

damage during shipping and installation, and with the opaque coating, provides protection from electric shock during installation.

3.1.4 Quick Electrical Connects

The fourth step in reducing shipping and installation costs was to eliminate electrical junction boxes and introduce quick connects. Junction boxes had to be glued to the top or bottom of the laminate. One junction box was required for each laminate and was shipped in a separate box along with one tube of adhesive for every three boxes. The fact that these were shipped separately caused confusion that often resulted in unnecessary delays. The junction boxes took about 5 to 10 minutes to adhere to the top or bottom of the laminate with plastic adhesive. The adhesive took from four hours to three days to dry depending on temperature and weather conditions. After the adhesive was dry, wiring could then proceed. First the wires from the laminates were screwed into the terminations in the junction box. Then conduit was placed between the junction boxes and the combiner boxes using conduit fittings. Next the wires that completed the series strings and parallel connections were screwed into the terminations in the junction box. The lids were screwed on to the junction boxes. All these processes were performed by expensive electrical contractors and took from 10 to 20 minutes per laminate to complete. This process contributed \$0.25 to \$0.50/Watt for the installation cost of site bonded PVL laminates.



Figure 5. Wiring at J-boxes w/ strain relief and series wiring

Photo Credit: Uni-Solar

The solution was to use the same UL and UV rated quick electrical connectors (see Figure 6) that are used on PV modules available from other manufacturers. These quick connects can be plugged together in seconds using less skilled labor. There were 15 pages in the previous installation manual describing the installation and wiring of the junction boxes, which were replaced by two pages describing quick connects.

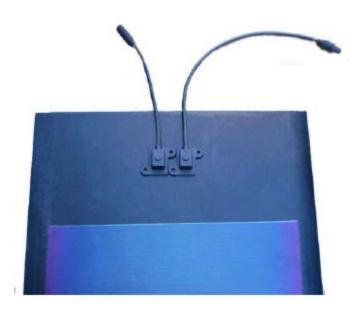


Figure 6. Quick connects
Photo Credit: Uni-Solar

3.1.5 Summary of Shipping and Installation Cost Savings—Impact of Final Results

Uni-Solar Building Integrated Photovoltaic (BIPV) laminates were originally only offered as a product factory-bonded to structural standing seam roofing. These factory bonded PV Roofing pans were very expensive to crate and ship. Crating costs were from 20 to 25 cents per Watt and shipping costs varied from 75 cents to \$2 per Watt. Long flatbed trucks were required to deliver the crates and were not always able to navigate country roads and driveways. In addition, unloading the large crates requires a forklift, which is not available on many residential job sites. The entire bill for crating, shipping, and forklift rental, as well as the cost of renting a smaller truck to maneuver on small country roads and driveways totaled \$2 to \$4/Watt. The combination of all the costs amounts to a potential savings of \$1.55 to \$12.54/Watt depending on degree of damage using the old installation procedures.

The performance goal for this project was to reduce the installed price of PV to \$5/Watt during the second year. The impact of the reduced cost of shipping and installation brings the installed price down to \$7-\$8/Watt. This compares to the cost of \$10 to \$15/Watt for installations done with the original factory-bonded product. Table 1 shows the results of a cost analysis with low and high estimates.

Estimates for costs of shipping both products were based on quotes obtained from shipping companies and from the experience of Uni-Solar product installers/distributors. Installation costs were based on previous installations of the Uni-Solar PVL product and estimates based on mock-ups of the PVR product.

Table 1. Summary of shipping and installation cost savings

Cost Saving Step	Original Install & Ship Cost –	Original Install & Ship Cost –	Reduced Install & Ship Cost – Low	Reduced Install & Ship Cost –
	Low Est. (\$/Watt)	High Est. (\$/Watt)	Est. (\$/Watt)	High Est. (\$/Watt)
	Ste			(4
Hand wrapped paper vs. machine applied	<\$0.01	<\$0.01	<\$0.01	<\$0.01
Cleaning surface vs. stripping protective coating	<\$0.01	<\$0.01	<\$0.01	<\$0.01
Replacing damaged laminates	\$0	\$6.00	\$0	\$0
	St	tep 2—Shipping Spo	ool	
Crating roof panels / vs. shipping spool for rolls of laminate	\$0.25	\$0.25	<\$0.01	<\$0.01
Shipping costs for roof panels vs. shipping cost for rolls of laminate	\$0.75	\$1.00	\$0.05	\$0.10
Forklift and truck rental	\$0.25	\$1.00	\$0	\$0
Cost of site bonding vs. factory bonding	\$0.30	\$0.50	\$0.20	\$0.60
		Step 3—Ridge Rolle		
Cost of damage caused by hand carrying laminates vs. cost of ridge roller and associated labor	<\$0.01	\$4.00	<\$0.01	<\$0.01
	St	ep 4—Quick Conne	cts	

Cost of gluing	\$0.25	\$0.50	<\$0.01	\$0.02
and wiring				
junction				
boxes vs.				
Cost of				
quick				
connects				
Total Costs	\$1.80	\$13.26	\$0.25	\$0.72

Data collected by Steve Heckeroth

3.2 Hardware Development and UL Approval

3.2.1 Developing PVR Kit Hardware, Including Drawings, Photographs and Descriptions of all Hardware

Development of the hardware was performed in several iterations. The original design concepts were developed and mockups were built. Then the design was revised three times:

- Original Design Concepts are shown in Figure 7.
- Design Revision 1 is shown in Figures 8, 9, and 10.
- Design Revision 2 is shown in Figures 11 and 12.

Note: The design was revised (Design Revision 3) one more time. Please refer to Section 3.2.5 (Further Clamping Batten Development Based on Findings from Roofing Tests).

The following discussion describes the reasons these design revisions were necessary and the approaches to developing them.

Original Design Concept

The first clamping batten design concepts and mock-ups (Figure 7) used exposed fasteners, which were aesthetically inferior and a possible source of moisture intrusion.

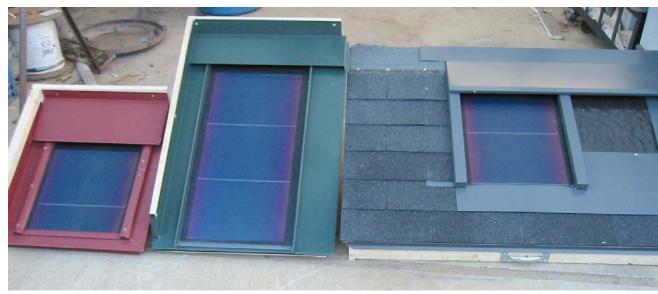


Figure 7. Original design concepts—clamping batten system mock-ups

Design Revision 1—Fully Overlapping Clamping Batten System with Base Channel

The next generation (Design Revision 1) of clamping battens sandwiched the laminates between a base channel and a U-channel using mechanical fasteners and clips to secure a snap-on cap (Figures 8 and 9). This technique created a weatherproof barrier without exposed fasteners. This system was used in the three field trial installations.

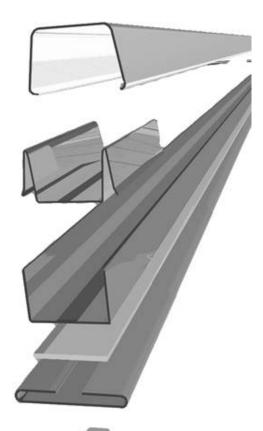


Figure 8. Design Rev. 1—clamping batten with base channel Photo Credit: Uni-Solar

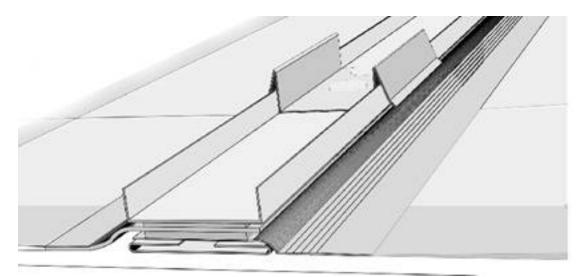


Figure 9. Design Rev. 1—clamping batten with base channel clamping strip Photo Credit: Uni-Solar

Design Revision 2—Partially Overlapping Clamping Batten System

Feedback from the first three field trials showed that the base channel could be eliminated. It also pointed out a weakness in the full overlap of the Design Rev. 1 clamping batten system. A new design was developed, Design Revision 2, in which the U-channel was modified to make a cavity which contains a butyl strip. The advantage is that the edge of the laminate is sealed by the butyl, which eliminates the possibility of moisture entering between the laminates. Additionally, the new clamping batten system was developed with a partial overlap so that the overlapping edge could be completely sealed under the clamping batten. Initial analysis of the new system indicated that it would provide a more durable weather barrier. Drawings are shown in Figure 10 below.

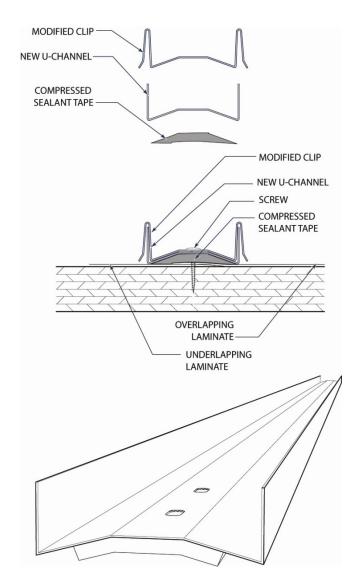


Figure 10. Design Rev. 2—improved clamping batten system Design with partially overlapping sealed edges

Photo Credit: Uni-Solar

A prototype of this design was built as shown in Figure 11. The approach of developing mock-ups and doing field trial installations resulted in the development of a clamping batten system that is a weatherproof, combination roofing and PV product. The product was made available as a PVR kit in several configurations to meet the needs of the average residential installation.

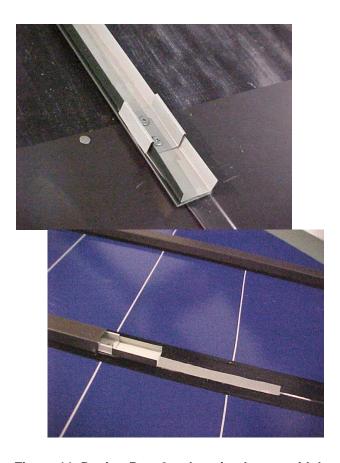


Figure 11. Design Rev. 2—clamping batten with base channel clamping strip eliminated Photo Credit: Uni-Solar

Cold climate testing of the Design Rev. 2 Clamping Batten System showed superior snow shedding capability, which increased kW performance. The smooth unobstructed TefzelTM surface sheds snow days ahead of equal size crystalline arrays, which dramatically increases winter kWh performance.

A prototype was created and field installed in Skandia, Michgan. The installation was monitored at Paton's Wind and Solar for power output and snow shedding qualities. Results from side by side tests with crystalline modules show that snow is shed on the prototype an average of two hours earlier than on the crystalline modules. The Skandia installation (Figure 12) is a small array of 3 PVL 87T laminates with a rated power of 0.261 kW.



Figure 12. Design Rev. 2—field installation clamping batten system prototype Photo Credit: Uni-Solar

The Skandia installation represented the first installation of the Design Rev. 2 clamping batten system, as well as a test study in laminate performance in snow country near the 45th parallel. It was compared to an array of glass modules in the same location for performance and snow shedding in a systematic manner. Initial observations have been that the Uni-Solar laminates have shed snow quickly while the glass modules have held snow for days at a time.

3.2.2 UL Listing of the PRV kit

The Design Rev. 1 Clamping Batten System with overlapping edges was selected for UL testing. An 8-foot-long test deck was delivered to the UL testing facility. This was tested by UL and the product achieved UL Listing. A copy of the UL certificate is shown in Figure 13.

Class A fire rating tests on low slope applications was conducted at UL on June 20 and 21, 2002. The results are summarized in Section 3.2.4.

333 Pfingsten Road Northbrook, Illinois 60052-2096 United States Country Code (1) (847) 272-6800 FAX No. (847) 272-8129 http://www.ul.com



NOTICE OF AUTHORIZATION TO APPLY THE UL MARK

Northbrook Office

June 20, 2002

United Solar Systems Corp Attn: Dr. Prem Nath 3800 Lapeer Rd Auburn Hills MI 48326

Our Reference:

File E182242, Project 02NK22919

Subject:

UL 1703 Listing fo clamped seam and batten roofing system, PVR

series

Dear Dr. Nath:

We have completed our engineering investigation under the above project number and find the products comply with the applicable requirements.

This letter temporarily supplements the UL Follow-Up Services Inspection Procedure and serves as authorization to apply the UL Listing Mark, only at the factory under UL's Follow-Up Service Program, to the above products, which are constructed as described below:

Identical to the subject model which was submitted to UL for this investigation, the UL records covering the product will be in the Follow-Up Services Inspection Procedure, File E182242, Volume2.

To provide the manufacturer with the intended authorization to use the UL Mark, the addressee must send a copy of this Notice and all attached material to each manufacturing location as currently authorized in the appropriate UL File Procedure.

This authorization is effective for 90 days only from the date of this Notice and only for products at the indicated manufacturing locations. Records covering the product are now being prepared and will be sent to the indicated manufacturing locations in the near future. Please note that Follow-Up Services Procedures are sent to the manufacturers only unless the Applicant specifically requests this document.

Products produced, which bear the UL Mark, shall be identical to those evaluated by UL and found to comply with UL's requirements. If changes in construction are discovered, authorization to use the UL Mark may be withdrawn and products that bear the UL Mark may have to be revised (in the field or at the manufacturer's facility) to bring them into compliance with UL's requirements.

Respectfully,

Steven Jockums (Ext. 42229)

Sr. Project Engineer

Conformity Assessment Services - 3013MNBK

E-mail: Steven. Jochums@us.ul.com

Daniel C Maher (Ext. 42930)

Engineering Group Leader

Conformity Assessment Services - 3013MNEK

E-mail: Daniel.C.Maher@us.ul.com

A not-for-profit organization dedicated to public safety and committed to quality service

Figure 13. UL listing document—June 20, 2002

Photo Credit: Underwriters Laboratories

3.2.3 Test Plan for Product's Performance as a Roofing System UL Test Plan

Because the PVR System does not rely on roofing substrates, it was realized that it needed to be tested as a full roofing solution, not just as a photovoltaic product. The task objective was to develop a list of roofing tests that would be performed to assure the PVR system's structural integrity and durability. Passing the tests would give building industry and code officials' confidence in the PVR system.

The UL Prepared Roof Covering Materials group was contacted to request approval for the PVR system and discuss what testing would be required to qualify the product as a roofing material.

UL testing was performed on PVR system Design Revision 2—Improved Clamping Batten System with partially overlapping sealed edges (Figure 10). The test assembly was comprised of a base sheet, slip-sheet, and a PV module with a self-adhering back surface (SIKA adhesive), quick connects, output cables and connecting system. The PV module acted as the roof covering exposed to weather. The PV modules were applied with an overlap seam. The overlapped portions of the module were covered with and mechanically attached with a batten/clip assembly.

Tests required by UL were conducted at their Northbrook, Illinois facility, including Electrical Test UL 1703, ANSI/UL 790 "Tests for Fire Resistance of Roof Covering Materials", and UL991 Wind Uplift Testing.

Results of these UL tests are included in the "UL Test Results" Section below.

Adhesive Test Plan

In addition, the following tests were to be completed at the Bekaert facility in Belgium:

- Shear Strength—ASTM D 1002—Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading.
- Peel Strength—ASTM D 903—Standard Test Method for Peel or Stripping Strength of Adhesive Bonds.

Adhesive tests were to be conducted at various temperatures between -40°F and 194°F (-40°C and 90°C). Adhesive tests were also to be completed before and after various aging has occurred—performed according to ASTM E1171—Standard Test Methods for Photovoltaic Modules in Cyclic Temperature and Humidity Environments:

- Damp Heat
- Heat Freeze
- Thermal Cycling

Results of the adhesive tests are included in the "Adhesive Test Results" Section.

3.2.4 Completion of Roofing and Adhesive Tests—Test Results UL Test Results

Tests results from the UL testing at the Northbrook, Illinois, facility for PVL series testing, UL 790 Fire Resistance Testing of the Clamped Seam & Batten System, and UL 991 Wind Uplift Testing on the Clamped Seam & Batten System were as follows:

- UL Fire Resistance Testing of the Clamped Seam & Batten System.
- UL approval was gained, based on the fire performance of the system when subjected to one intermittent flame test and one burning brand test, and further testing was waived.
- UL991 Wind Uplift Testing of the Clamped Seam & Batten System.
- The forces required to lift a self-adhered PV module from the surface of the panel will be more than the forces required to lift the panel itself to the point of failure.
 PV modules may be applied to any roof panel construction within the category TGKX (Roof Deck Constructions).

Adhesive Test Results

Adhesive tests were completed at the BTC in Belgium. Preliminary results show the new SIKA adhesive to be superior to the existing MFM in all temperatures and no slippage occurred at 90°C (194°F) on a vertical surface.

Summary of Test Results

UL approval was gained for the Clamping Batten and Seam PV Roof Assembly, consisting of photovoltaic laminate assemblies, mechanically attached with battens and clips.

Although some of the UL tests were completed on earlier versions of the PVR system, it was determined by UL that tests did not need to be repeated with the newer design in order to obtain approval. This is often the case when the design changes are determined by UL to have no adverse affect on the test results.

UL approval was given on July 20, 2002, for PVR Revision 2—Improved Clamping Batten System with partially overlapping sealed edges. Approval was based on the PVR system with quick connects and Sika adhesive. See Figure 14 for a copy of the listing in the 2003 Roofing Materials and Systems Directory published by UL.

2003 ROOFING MATERIALS AND SYSTEMS DIRECTORY

06	ROOF COVERING MATERIALS (TEVT)	ROOF COVERING MATERIALS (TEVT)
	Roofing Systems (TGFU)-Continued	Roofing Systems (TGFU)-Continued
1. 2. 3.	Surfacing: Gravel, 400 lbs/sq or slag, 300 lbs/sq. Incline: 1-1/2 Foam: Polythane Systems "5200-25/30", 2 in thick. Surfacing: "Diathon", 2 coats, 1-2 gal/sq/coat. Deleted Deleted Deck: NC Foam: Foam Enterprises "FE-303", any thickness. Base Coat: "Elastuff 101 moisture cure base coat" (various colors) 1-1/4 to 2 gal/sq total (20-32 wet mils). Surfacing: "Elastuff 102" (various colors), 1-1/4 to 2 gal/sq total (20-32 wet mils). TED SOLAR SYSTEMS CORP 500 LAPEER RD, AUBURN HILLS MI 48326	Building Unit: Field-Assembled Photovoltaic (Solar) Module Systems, "PVL-29, -58, -60, -64, -87, -116, -120 or -128", self-adhered. Class C 1. Deck: C-15/32
7	OTHERS SYSTEMS	Gypsum Dens-Deck®, 1/4 in thick min. Slip Sheet (Optional): Elk "VersaShield", mechanically attached.
1.	Deck: C-15/32 Incline: 2	Building Unit: Field-Assembled Photovoltaic (Solar) Module Systems, "PVL-29, -58, -60, -64, -87, -116, -120 or -128", self-adhered .
	Slip Sheet: One layer Elk "VersaShield FB-15", mechanically attached. Ply Sheet: One layer Type 30 felt, mechanically attached. Building Unit: "Clamping Batten and Seam PV Roof Assembly", consisting of photovoltaic laminate assemblies, mechanically attached with battens and clips. Deck: NC Slip Sheet (Optional): Elk "VersaShield", mechanically attached. Base Sheet (Optional): Type 15, 30, G1 or G2, mechanically attached or hot mopped.	UNITED STRUCTURES OF AMERICA INC 1912 BUSCHONG, HOUSTON TX 77039 Class A 1. Deck: NC Incline: Unlimited Impact: Class 4 Surfacing: "A" Wall Panel, "Guardian I or II" Panels, "Guardian - LOK" Panel, "PBR" Panel, "R" Panel, "Supreme LOK" Panel, "Sure - LOK" Panel.
	Membrane: Sarnafil "S327", "S327/Felt", "S327-12", "S327-12/Felt", "S327-15/Felt", "S327-15/Felt", "S327-20/Felt", or "S327-24" (PVC). Building Unit: Fleld-Assembled Photovoltaic (Solar) Module Systems, "PVL-29, -58, -60, -64, -87, -116, -120 or -128", self-adhered.	UNITED STRUCTURES OF AMERICA INC R9610 1912 BUSCHONG, HOUSTON TX 77039 OTHER SYSTEMS Class A
	Deck: NC Slip Sheet (Optional): Elk "VersaShield", mechanically attached. Base Sheet (Optional): Type 15, 30, G1 or G2, mechanically attached or hot mopped. Membrane: Tremco "TremPly HP-4510" (CSPE). Building Unit: Field-Assembled Photovoltaic (Solar) Module Systems, "PVL-29, 55, -60, -64, -87, -116, -120 or -128", self-adhered. Deck: NC Slip Sheet (Optional): Elk "VersaShield", mechanically attached. Base Sheet (Optional): Type 15, 30, G1 or G2, mechanically attached or hot mopped.	 Deck: C-15/32 Incline: Unlimited Impact: Class 4 Barrier Board: 1/4 in. (min). G-P Gypsum Dens-Deck® with all joints staggered a min of 6 in. from the plywood joints. Ply Sheet (Optional): Any UL Classified Type GI, G2 or G3 base/ply sheet, Type 15, 20 or 30 felt or UL Classified prepared roofing accessory or WR Grace "Ice and Water Shield". Surfacing: Coated Steel roofing panels, mechanically fastened. Panels: "U.S.A.R", "Guardian I" or "Guardian II", "Guardian-Lok", "Sure-Lok", and "Supreme-Lok".
	Membrane: Johns Manville "SR-50", "SR-60, "SR-60 Premier" or "SR-80"	UPACO, DIV OF WORTHEN INDUSTRIES INC R18176 3 E SPIT BROOK RD, NASHUA NH 03060
	Building Unit: Field-Assembled Photovoltaic (Solar) Module Systems,	Class A - Ballasted 1 Deck: NC Incline: 2.
5.	"PVL-29, -58, -60, -64, -87, -116, -120 or -128", selt-adhered . Deck: NC Incline: 2 Panels (Optional): Any UL Classified standing seam roof panel. Barrier Board (Optional): Gypsum wallboard, 1/2 in. thick min., or G-P Gypsum Dens-Deck®, 1/4 in. thick min. Slip Sheet (Optional): Elk "VersaShield", mechanically attached. Building Unit: Field-Assembled Photovoltaic (Solar) Module Systems, "PVL-29, -58, -60, -64, -87, -116, -120 or -128", self-adhered .	1 Deck: NC Insulation: Polyisocyanurate, glass fiber, perlite, wood fiber, any combination, any thickness, loose laid or mechanically fastened to deck. Membrane: Any UL Classified EPDM. Adhered to insulation with "Upaco 3840G", "Upaco 1944" or "Upaco 5238" bonding adhesive at 60 sq ft/gal. Surfacing: River bottom stone (3/4 to 1-1/2 in. diameter) at 1000 lbs/sq.
1.	Class B Deck: C-15/32 Incline: 3	USG INTERIORS INC
2.	Slip Sheet: One layer Elk "VersaShield FB-15", mechanically attached. Ply Sheet: One layer Type 30 felt, mechanically attached. Building Unit: "Clamping Batten and Seam PV Roof Assembly", consisting of photovoltaic laminate assemblies, mechanically attached with battens and clips. Deck: NC Incline: 1	125 S FRANKLIN ST, CHICAGO II. 60606 ASPHALT FELT SYSTEMS WITH HOT ROOFING ASPHALT Class A 1. Deck: NC Insulation: "Structodeck", 0.450 to 2.25 in., mechanically fastened with metal insulation anchors or hot mopped. Base Sheet: Three to five layers Type 15 perforated felt or Type GI
	Slip Sheet (Optional): Elk "VersaShield", mechanically attached. Base Sheet (Optional): Type 15, 30, Gl or G2, mechanically attached or hot mopped. Membrane: Sarnafii "G410", "G410/Felt", "G410-12", "G410-12", "G410-16", G410-15", "G410-15', "G410-18", "G410-18/Felt", "G410-20", "G410-	Base Sheet: Three to five layers Type 15 perforated felt or Type Gl asphalt glass fiber ply sheet. Surfacing: Gravel, crushed stone or slag. SINGLE PLY MEMBRANE ROOFING SYSTEMS In mechanically fastened systems using Carlisle NP membrane anchors, fastening consists of plastic base plates, plastic retainers and plastic caps. The base plates are installed over the deck 3 ft. OC max in each direction and
	20/Felt" or "G410-24" (PVC). Building Unit: Field-Assembled Photovoltaic (Solar) Module Systems,	
3.	"PVL-29, -58, -60, -64, -87, -116, -120 or -128", self-adhered . Deck: NC Panels (Optional): Any UL Classified standing seam roof panel. Barrier Board (Optional): Gypsum wallboard, 1/2 in. thick min., or G-P Gypsum Dens-Deck®, 1/4 in. thick min. Slip Sheet (Optional): Elk "VersaShield", mechanically attached.	secured to deck with metal fasteners. The membrane is secured by pressing the plastic retainers over the base plate knobs. The plastic caps are placed on top of the retainers, pressed onto the retainers and hand tightened to provide a snug fitting connection. Field applied membrane splices 3 to 4 in, wide are adhered with Carlisle N-100 splicing cement, 2 gal/sq sealed with Carlisle Lap Sealant, 11 oz/10 ft of joint. Field splices are located a min of 1 ft from the NP membrane anchors.

Figure 14. UL 2003 roofing materials and system directory listing

Photo Credit: UL 2003 Roofing Materials and Systems Directory

3.2.5 Further Clamping Batten Development Based on Findings from Roofing Tests

The first three field trials showed a weakness in weather tightness and stability of the clamping batten system of the full overlap of the clamping batten system. The original four-piece clamping batten system (Rev. 1) with fully overlapping edges and MFM adhesive was revised to create an improved three-piece clamping batten system (Rev. 2) with partially overlapping edges adhered with new SIKA adhesive. The roofing test showed successful testing on improved adhesives.

The first three field trials also revealed that the cost of manufacturing and shipping the Rev. 2 clamping batten system was high, because the components, a hand fabricated U-channel, the clips, and battens, could only be made by a metal roofing fabricator who had the appropriate equipment and experience. Other metal roofing suppliers were contacted; however, they were not able to even provide quotes on the components. This hand fabrication added to the cost and manufacturing lead-time for the product.

To resolve this problem, a new two-piece clamping batten system (Rev. 3) was researched that employs a commercially available insert molding component already manufactured for the recreational vehicle market. The new clamping batten system (Design Revision 3) components are pictured in Figure 15.





Figure 15. Design Revision 3—insert molding components

Photo Credit: Uni-Solar

The flush insert is screwed down over double-stick butyl tape, creating a weatherproof barrier at the overlapping joints by applying pressure to adhesives that act as a gasket. A vinyl insert screw cover is inserted to provide a superior waterproof barrier to prevent water penetration at the screws.



Figure 16. Design Revision 3—insert molding clamping batten system Photo Credit: Uni-Solar

The Insert Molding Clamping Batten System is the final configuration (Design Rev. 3) of the project. This design revision was first put to practice at a field trial in Sacramento. The installation proved to be easier and faster than the installation of previous revisions. Other advantages are the components were very inexpensive, readily available from a number of sources, and can be shipped by UPS in a shipping tube, rather than a metal roofing crate. The insert molding is screwed down every 4 inches through double-stick butyl tape, offering superior resistance to wind and water intrusion.

One originally proposed innovation, inexpensive non-active roll roofing, was found to be unworthy of further research and commercialization. Preliminary analysis was done on seven different options for non-active roll roofing materials. Research was conducted and the selection was narrowed down to three membrane type roofing materials. They are TPO, EPDM, and Hypalon. All of these materials have a Class A fire rating when used in conjunction with a flame retardant substrate. TPO usually comes in white. EPDM is usually black. Hypalon is available in a wide range of colors. It was determined that development of non-active laminate material for the balance of the roof may be more expensive than metal roofing. It was decided that the focus would be on making laminates available in additional lengths to accommodate complex roof shapes rather than developing non-active PV roofing. In addition, several termination strategies were developed to accommodate roofs that would require two or more laminates to achieve the desired length. These are described in the following Section 3.2.6.

3.2.6 Termination Strategies

The availability of limited laminate lengths (up to 18 feet) necessitated development of mid-roof electrical termination strategies to cover more area with PV on large roofs. Termination strategies for above roof connections and end-to-end connections between laminates were designed and prototypes were made. Following are photos of mock-ups of the ridge cap and head flashing termination strategies.



Figure 17. Perforated Z closure Photo Credit: Uni-Solar



Figure 18. Ridge cap fastened to Z closure to conceal the wiresPhoto Credit: Uni-Solar



Figure 19. Z closure and riglet in place Photo Credit: Uni-Solar

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Figure 20. Fastening of the head flashing Photo Credit: Uni-Solar

This task included the development of termination strategies to electrically connect laminates together to satisfy the need for covering odd shaped roof areas. The absence of longer laminates to cover roofs larger than 18 feet (the longest laminate length) from ridge to eave necessitated the development of mid-roof termination strategies.

There were six above roof termination strategies identified and mock-ups were made based on connection to the second generation clamping batten covers. The third generation clamping batten system utilizing insert molding did not provide a place to fasten four of the strategies. The only above roof strategies that can be used with the third generation insert molding clamping battens are the ridge cap (Figure 21) and head flashing (Figures 22 and 23) termination strategies.

The end-to-end termination was fully developed and initial designs on a laminating machine were completed, but Uni-Solar manufacturing has no plans to produce this option at this time. All of these electrical termination strategies allow full coverage of larger roof areas.

Field applied bottom termination (terminations in the eave soffit) were determined to be unfeasible because of the difficulty of penetrating the roof deck and protecting wiring in the soffit area from water. Terminations under the ridge cap are a superior solution.

Ridge Cap Termination

Ridge cap termination is a standard method of termination for PVL product. This is now made much easier with the use of quick connects, which are easily protected under the ridge cap.

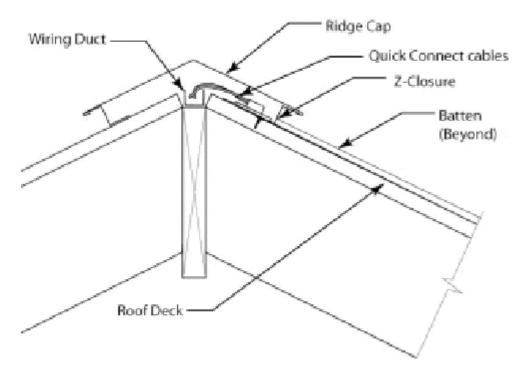


Figure 21. Ridge cap termination strategy

Head Flashing Termination

Head flashing mock-ups were done which showed that the original concept of a one-piece head flashing did not offer acceptable access to the wiring terminations. Therefore a design and mock-up of a two-piece head flashing was completed.

Head flashing is one mid-roof termination strategy, but is expensive and requires an interruption in the battens.

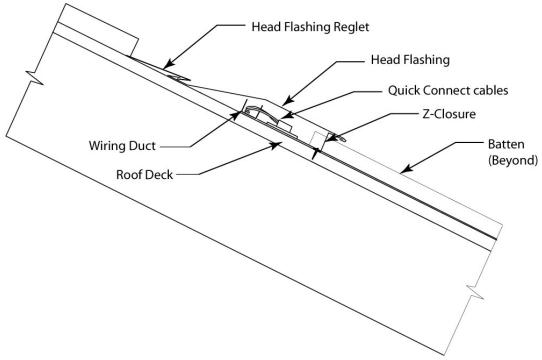


Figure 22. Two-piece removable head flashing

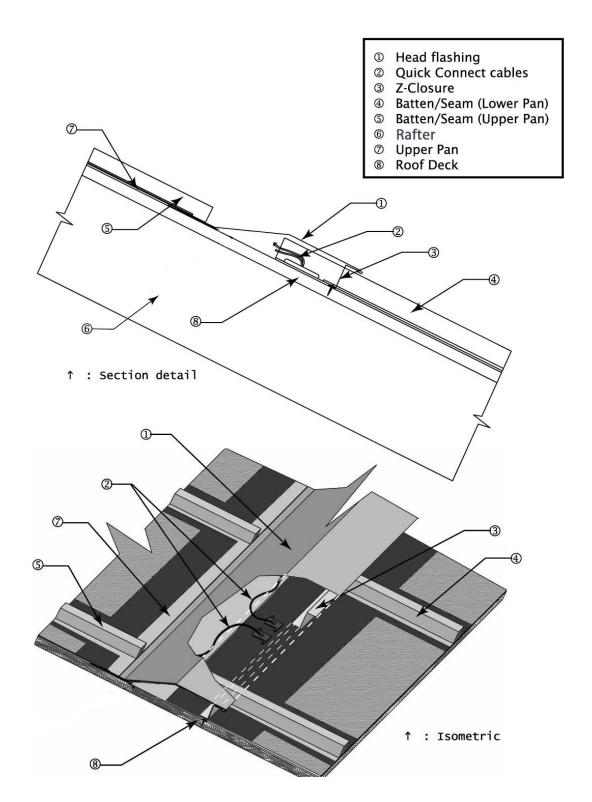


Figure 23. Mid-roof termination detail

End-to-End Terminations

It has been determined that the best interim full roof solution using current laminate lengths can be accomplished by using end-to-end terminations. The most promising termination strategy is illustrated in Figures 24 through 27. This strategy relies on connecting the top laminate termination to the bottom of the next laminate to create a series string.

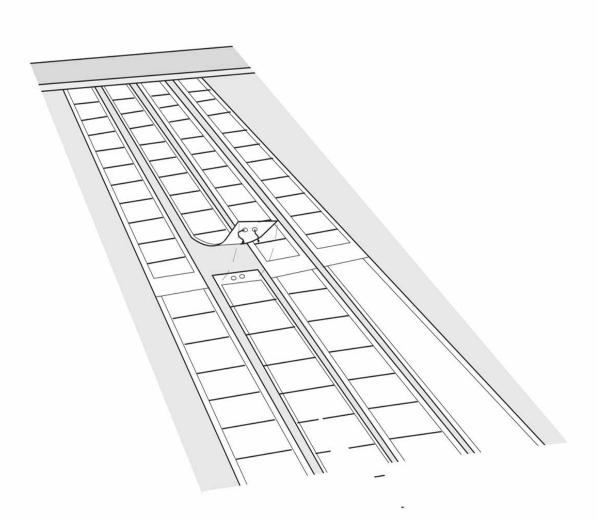


Figure 24. End-to-end terminations

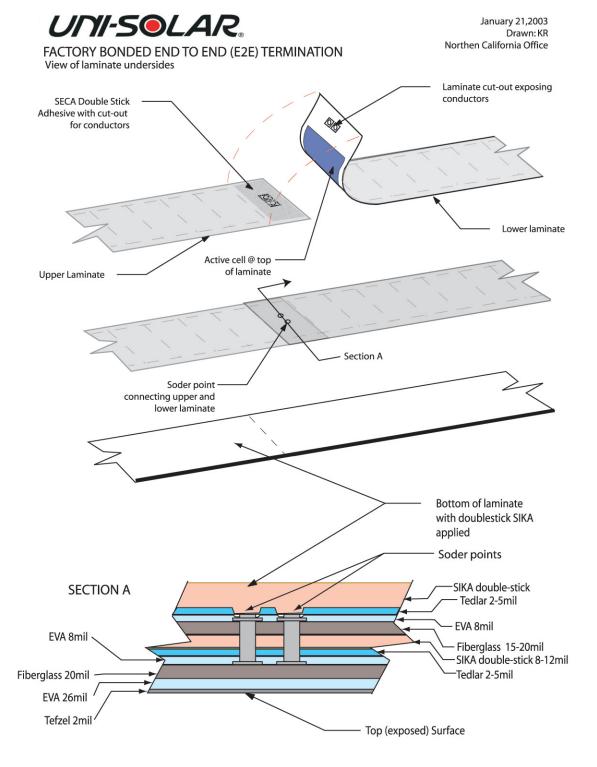


Figure 25. End-to-end laminate connection

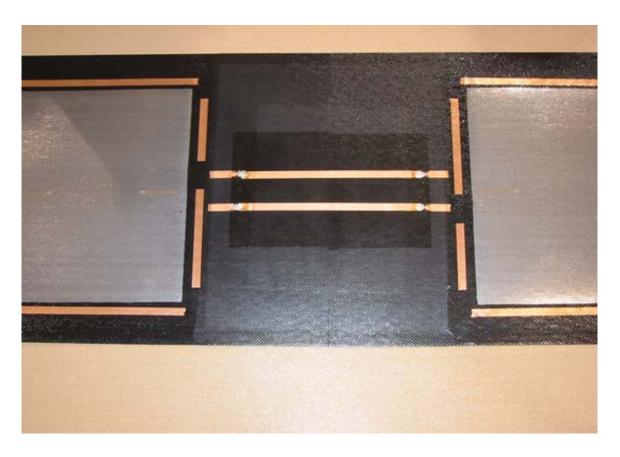


Figure 26. Factory laminated end-to-end connection underside Photo Credit: Uni-Solar

Further development of factory bonded end-to-end terminations was completed. A mock up of a third design for the end-to-end connection was completed and shows great progress. The distance between the cells where the joint is made has been reduced to 2 ¾ inches and the joint has about the same flexibility as the rest of the laminate. Figure 27 shows a picture of the joint, as it will appear on the roof. No flashing is needed. No special installation techniques will be required. Because the terminations are done in the factory, no further UL testing will be required.

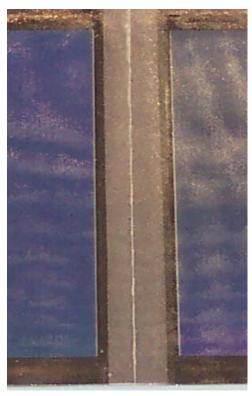


Figure 27. Third design for end-to-end connection with only 2 ¾ inch gap between cells

Termination Strategy Summary

The terminations under the ridge cap will continue to work for 18 foot laminates with top termination. On roofs that are greater than 18 feet from ridge to eave, only the head flashing will provide a mid-roof termination strategy if insert molding is used for the clamping batten system. End-to-End termination would provide a strategy for full roof coverage with PV laminates on large roofs, should Uni-Solar decide to manufacture this in the future.

3.3 Class A Fire Rating

3.3.1 Obtaining a Class A Fire Rating for Low Slope Applications

Membrane roofing manufacturers advised that Class A fire rating could be obtained for low pitch installations (less than 3:12) by using fire retardant substrates in a roofing system.

Research has been completed on several flame retardant substrates that satisfy the burn through requirement of tests for Class A fire rating. Of the underlayments identified to help achieve Class A fire rating, VersaShield was identified and used successfully in the UL fire rating test.

The Design Rev. 1 Clamping Batten System with overlapping edges was selected for UL testing, which included procedures for fire rating. Samples were subjected to UL test procedures for "burn through" and "flame spread." All samples passed the "burn though" test for Class A fire rating on all slopes with Elk VersaShield underlayment installed underneath the PV Roofing.

"Flame spread" tests with Elk VersaShield underlayment produced Class A rating on a maximum slope of 2:12, and a Class B rating on a maximum slope of 3:12 and a Class C rating on unrestricted slope.

The Class A fire rating approval was given by UL on June 20 on low pitch slopes. The official UL letter, shown as Figure 28 was received on August 14, 2002.

North Carolina • (919) 549-1400 Camas, Washington • (360) 817-550

Underwriters Laboratories Inc. ®

UNITED SOLAR SYSTEMS CORP DR P NATH 3800 LAPEER RD AUBURN HILLS MI 48326

RE: Project Number(s) - 02NK22559

Your most recent Certification is shown below. You may also view this information, or a portion of this information (depending on the product category), on UL's Online Certifications Directory at www.ul.com/database. Please review the text and contact the Conformity Assessment Services staff member who handled your project if revisions are required. For instructions on placing an order for this information in a 3 x 5-inch format, you may refer to the enclosed order form for UL Card Service.

TGFU Roofing Systems August 14, 2002

UNITED SOLAR SYSTEMS CORP 3800 LAPEER RD, AUBURN HILLS MI 48326

E182242

OTHERS SYSTEMS

Class A

1. Dedc C-15/32

Slip Sheet: One layer Elk "VersaShield FB-1S", mechanically attached.

Ply Sheet: One layer Type 30 felt, mechanically attached.

Surfacing: "Clamping Batten and Searn PV Roof Assembly", consisting of photovoltaic laminate assemblies, mechanically attached with battens and clips.

1. Dedc C-15/32

Incline: 3

Slip Sheet: One layer Elk "VersaShield FB-15", mechanically attached.
Ply Sheet: One layer Type 30 felt, mechanically attached.
Surfacing: "Clamping Batter and Seam PV Roof Assembly", consisting of photovoltaic laminate assemblies, mechanically attached with

battens and clips.

1. Decks C-15/32

Decks C-15/32 Incline: Unlimited Slip Sheeb One layer Elk "VersaShield FB-15", mechanically attached.

Phy Shaet: One layer Type 30, felt mechanically attached.

Surfacing: "Clamping Batten and Seam PV Roof Assembly", consisting of photovoltaic laminate assemblies, mechanically attached with battens and clips.

The photovoltzic (PV) roof assembly is also Lised as Photovoltzic Module and Panels (QEGU). See the Electrical Equipment Directory.

LOOK FOR CLASSIFICATION MARK ON PRODUCT

861778002

Page 1 of 1

A net-for-profit organization dedicated to public safety and

Figure 28. UL approval letter

Photo Credit: Underwriters Laboratories

3.3.2 Feasibility Report on Obtaining Class A Fire Rating on Slopes Over 2:12

After researching the possibility of obtaining Class A fire rating on slopes over 2:12, four alternatives were investigated:

- 1. Reducing the thickness of EVA adhesive in the laminate.
- 2. Testing alternative adhesives/encapsulants.
- 3. Using fire retardant substrates in the roofing system.
- 4. Adding fire retardant materials to the EVA compound.

The results were reported as follows:

- 1. Reducing the thickness of EVA adhesive in the laminate: No known results. It is very risky to decrease the thickness of EVA as it is likely to cause other problems to occur in the process.
- 2. Testing alternative adhesives/encapsulants: No known results. No alternative adhesives/encapsulants were identified as potential candidates.
- 3. Using fire retardant substrates in the roofing system:
 - Membrane roofing manufacturer advised that Class A fire rating could be obtained for low pitch installations (equal to or less than 2:12) by using fire retardant substrates in a roofing system.
 - Research has been completed on several substrates that satisfy the burn through requirement of tests for Class A fire rating. The same substrates will not satisfy the requirement for flame spread on roof pitches over 2:12.
 - VersaShield was identified and used successfully in the UL fire-rating test.
 Refer to UL rating letter dated August 14, 2002.
- 4. Adding fire retardant materials to the EVA compound:
 - Research on flame retardant substrates was completed and several flame retardant substrates were identified: Somasif® MAE, Nanofil® 15, Cloisite® 25A, Cloisite® 30B, and Dellite® 26C.
 - BTC had been doing exhaustive studies on various additives to the EVA that is the flammable part of the laminate to decrease flammability.
 Preliminary results suggest that higher fire ratings may be obtainable with minor influence on long-term transparency.
 - As a result of the testing, the EVA additives were narrowed down to Somasif® MAE and Cloisite® 25A. These two nanoclays give the best properties in terms of light transmission, thermal degradation delay, and fire retardancy (charring).

• Extensive fire testing on various materials were performed and are available in deliverables 3.1.3.2. Feasibility Report on Obtaining Class A on Slopes >2:12. Following are summary results of the work:

1. Light Transmission

Sample	Amount of Total Light Transmitted relative to the matrix alone (%)
EVA	100
+Cloisite 25A	90.3
+Somasif MAE	87.2
EVA compound	100
+Cloisite 25A	97.6
+Somasif MAE	90.5

2. Thermal Degradation Delay (Thermogravimetric Analysis)

Sample	Max. Temp. for 1 st degradati on °C	Max. Temp. for 2 nd degradati on °C	Temp. of 2 nd degrad ation end °C
EVA	368	472	519
+3wt% Cloisite 25A	354	495	520
+3wt% Somasif MAE	368	495	528
EVA compound	370	474	516
+3wt% Cloisite 25A	353	493	518
+3wt% Somasif MAE	368	491	523

Sample	Burning Droplet s	Charring	Sparks
EVA	Yes	No	No
+Cloisite 25A	No	Yes	No
+Somasif MAE	No	Yes	No
EVA compound	Yes	No	Yes
+Cloisite 25A	No	Yes	Yes
+Somasif MAE	No	Yes	Yes

3. Fire Retardancy (Burning Behavior)

BTC was successful in identifying additives to the EVA to decrease flammability while only reducing transparency by 2%.

Conclusion

Based on the results of the research that was conducted, it appears that the only way to obtain a Class A fire rating on slopes ore more than 2:12 is to add flame retardant additives to the EVA. While it is clear that these additives will improve the flammability, it is not clear that this improvement will be enough to pass Class A fire testing. The only way to determine this is to make samples of EVA with fire retardant additives in the proper thicknesses and perform fire testing on PV modules created from them.

3.4 Training Programs

3.4.1 Website Improvement—Software Design and Development

The cost and sizing software called Clean Power Estimator was made available on the Uni-Solar website at www.uni-solar.com. This software allows the potential customer to enter their project specific data and receive performance output and cost information.

Electricians, roofers, and solar contractors were contacted to provide input necessary to design the software. They helped the software development team to define design and application techniques, thus assuring that the software would satisfy their needs.

To use the Clean Power Estimator, the user enters their zip code and customer type (commercial or residential). The program then estimates the feasibility of a clean energy system in that customer's location. If the zip code field is left blank, then a list of electric rates will appear on the subsequent screens.

The program uses the customer inputs and combines them with pre-collected data (electric rate schedules; Federal and State income tax rates; Federal, State, and utility economic incentives; local weather data; electric load profiles; and clean energy system performance) and analyzes the information using published research methods. The program includes potential economic incentives and tax benefits of purchasing a renewable energy system.

3.4.2 Completion of Owner's Manual

An Owner's Manual was completed in March 2003, which included kit sizes and complete lists of hardware needed. The manual provided step-by-step instructions on how to install the Design Revision 2 PVR system on the roof.

3.4.3 Completion of Training Materials

An Installation and Training Manual for the PVR was completed. The manual details the necessary procedures for installing a Design Revision 3 (Insert Molding) PVR system.

3.5 Demonstration Field Trials

3.5.1 First Field Trial Installation—Wayne, Pennsylvania

The first field trial was installed on June 5, 2002, at Chanticlear—a public garden located at 812 Church Road in Wayne, Pennsylvania.

General Information

The 1.28 kW PVR kit installation was done over an 8:12 pitch shingle-roofed garage located near Philadelphia, PA. The array is comprised of 20 untrimmed PVL 64 laminates overlapped at the edges and fastened to the roof deck using the UL listed Clamping and Batten system the grant team had developed. The representatives present for the installation included:

- Don Bradley of Solar Strategies, the general contractor who secured the job and electrical permit.
- Dan Perkins and his employee, Jared Vickstrom, members of the grant team that fabricated and installed the array.
- Dennis Hill, a Uni-Solar employee who filmed the installation and helped with the DC wiring of the array.
- The contact at Chanticlear is Chris Woods.

A Class A fire rating was not required for this first installation.

Installation Procedures

The step-by-step procedure in the PVR Kit Manual was followed to complete this installation:

- 1. Roof Top Guard was applied on top of existing shingles where the array was to be installed.
- 2. The border of the array was trimmed with custom folded flat stock steel.
- 3. Base channel was laid out 16 ½" on center.
- 4. Laminates were installed so that they adhered to Roof Top Guard membrane and base channels.
- 5. U-channels and clips were installed over base channels.
- 6. Battens were snapped onto clips.
- 7. Z-channel was installed.
- 8. All boxes and wiring were installed for DC side of the array on the roof. Wiring was brought to a combiner box on the inside of the roof structure.
- 9. Ridge cap was installed over wiring.

Installation Costs

The cost of the installation was high, almost \$17/Watt, because of the available components: field applied Butyl tape, a partial trim and flashing kit that had to be completed on site, and junction boxes, as well as unusual travel expenses.

A few additional factors increased the per Watt cost:

- 1. The small size of the PV system meant that the inverter was twice as big as the system required. The balance of system (BOS) cost was the same as for an array twice the size.
- 2. The cost of travel for Dan Perkins and Jared Vickstrom divided over the small array also put unusual cost factors into the equation. Normally a local firm would do an installation of that size.
- 3. The cost of manufacturing of the batten system was a prototype cost. Many of the techniques for manufacturing the batten system were under development and not as efficient as they could be. The custom trim work had to be done twice due to poor field measurements.

Table 2. Breakdown of installed cost for Field Trial No. 1—1.280 kW PV system

Materials	\$ Total	\$/Watt		
PV Laminates	4,920	4.13		
Inverter and electrical balance of system	2,500	1.95		
Batten, flashing, & trim kit	3,847	3.01		
Miscellaneous (4% of total materials)	450	0.35		
Labor				
Installation PV laminates	2,030	1.59		
Installation electrical	1,680	1.32		
Total Installed Cost	15,427	12.35		
Site Specific Costs				
Travel	4,121	3.22		
Permits, reports, interconnection agreements	1,500	1.17		
Total Site Specific cost	5,621	4.39		
TOTAL OVERALL INSTALLED COST PER WATT = \$16.74				

Data collected by Steve Heckeroth

Photos of installation—Wayne, Pennsylvania



Figure 29. Prior to install

Photo Credit: Uni-Solar



Figure 30. Roofguard underlayment installed



Figure 31. Clamping strips installed.

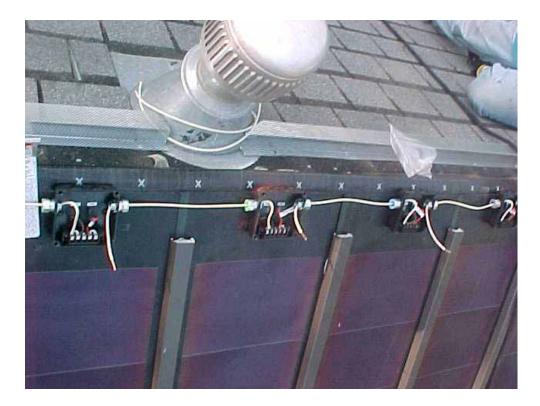


Figure 32. Wiring at J-boxes w/ strain relief and series wiring. Photo Credit: Uni-Solar

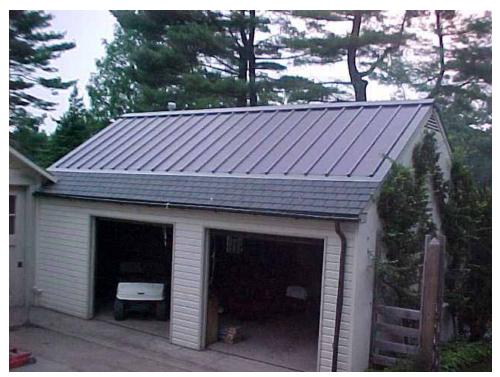


Figure 33. Completed PV roof w/ ridge cap installed.

3.5.2 Second Field Trial Installation—Franklin Park, Virginia

The second field trial (1.9 kW system) was installed October 3 through October 6, 2002, at Franklin Park, Virginia.

The array consists of 22 untrimmed PVL 87 modules on a 4:12 roof slope using an SMA 1800 inverter. This was the first field trial to incorporate potted quick connects, opaque protective covering, and PVR batten, flashing and trim kit interfacing with architectural metal roofing. These improvements cut installation time and cost to almost half of what it was on the first field trial.



Figure 34. Franklin Park 1.9 kW installation

3.5.3 Third Field Trial Installation—Eureka, California

The third field trial was installed on the Californians for Alternatives to Toxics (CAT) headquarters in Eureka, California, in October 2002. It is a 100-year-old building in the historic district.

The system installed was a 2.55 kW array comprised of 22 untrimmed PVL 116 laminates overlapped at the edges and fastened to the roof deck using the UL listed Clamping and Batten system developed by the grant team. The project was done in conjunction with a re-roofing job that was already scheduled. Therefore there was no preparation costs included. The roof area covered and the system size were optimized which lowered the overall cost per Watt. The aesthetics of this project were superior because the laminate length and system size allowed for full roof coverage.



Figure 35. The completed installation with superior aesthetics Photo Credit: Uni-Solar

3.5.4 Fourth Field Trial Installation—Sacramento, California

The fourth field trial was installed on October 29 to 30, 2003, on a shed at SMUD's Hedge Substation in Sacramento, California. Present for the installation on October 29 were:

- 1. Solar Contractor, Team Solar: Rick Lavezzo, Gary Lavezzo, and crew.
- 2. Uni-Solar Construction Manager Dennis Hill.
- 3. Grant Manager Steve Heckeroth.

Present on October 30 for the presentation:

- 1. Solar Contractor, Team Solar: Rick Lavezzo, Gary Lavezzo, and crew.
- 2. DC Power: Joseph Marino.

- 3. Energy Commission: Joe McCabe.
- 4. SMUD: Ruth MacDougall, Bruce Vincent, Cliff Murley, Mike DeAngelis, Jon Bertolino, Grant Nelson, Jeff Kosinski, Mike Keesee, Mike Zannakis, Adel Suleiman, Brent Sloan, Hector Ortiz and videographer Robert Tokunaga.
- 5. ECD: Ben Ovshinsky.
- 6. Grant Manager Steve Heckeroth.

General Information

The system installed was a 1.9 kW array comprised of 22 PVL 87 laminates trimmed to 17" wide. The laminates were laid over 30 lb felt and a fireproof layer of VersaShield FB-1S. The edges were overlapped and fastened to the roof deck using the Insert Molding Clamping Batten system developed by the grant team. The crew of four people installed the array in approximately five hours. The project is complete and ready for viewing at the SMUD Hedge Substation at 9268 Tokay Road.

Installation Procedures

This is the first installation where the Insert Molding Clamping Batten system was used. During the second day, the grant manager made a presentation to representatives from the California Energy Commission and the Sacramento Municipal Utility District and a training video was made while the last two laminates were being installed. Following is a list of steps involved in completing the installation:

- 1. A layer of 30 lb. felt and a layer of VersaShield were applied to the exposed plywood deck.
- 2. Bottom flashing and rake trim were applied around the edge of the array.
- 3. The centerline of the array was determined and chalk lines were snapped at 16 inches over-center across the roof.
- 4. Laminates were installed so that they adhered to the VersaShield and bottom flashing with recorder inch overlap at the edges.
- 5. Insert Molding Clamping Battens were installed over the overlapping edges.
- 6. The Insert Molding was screwed down at 4-inch intervals.
- 7. The flexible insert was installed to cover the screws.
- 8. Z-channel was installed.
- Quick connects were plugged together under the ridge cap in two series strings.
 Two wires from each string were run in conduit down the side of the building to the DC disconnect and then on to the inverter.
- 10. The ridge cap was installed over wiring.

11. Connection from the inverter to the AC disconnect was made and the installation was completed.

Issues, Results, and Evaluation

This was the first field trial to incorporate laminates from the new Uni-Solar 30 MW annual production Auburn Hills factory. Many in attendance mentioned that the uniform color was a great improvement. However, the small allowable penetration areas at the terminal end of the laminate were seen as a problem. To ensure that penetrations would not be made outside the allowable area the Z closure had to be trimmed which was a time-consuming process that left sharp metal edges and significantly increased the chance of puncturing the laminate. Other improvements requested were a uniform aesthetically pleasing full roof solution and a narrower protective coating, as discussed below.

Full Roof Solution

• This project was 30-feet from peak to eave. As a result, a full roof solution could be not be demonstrated.

This installation underscored the need for a uniform full roof solution. Not many projects will match the lengths of PVL laminates that are now available. Therefore the need for longer laminates in one-cell increments and custom balance of system components was again identified.

Review of Supplied Balance of System Components

- The kit approach requires that every conceivable possibility needs to be considered. This leads to superfluous and additional components, which results in added material and shipping cost. It further results in extra material being left over after the job is completed that may end up in the waste stream if it cannot be applied elsewhere.
- Uni-Solar should further analyze which components can be sourced locally. In this case, the experienced local solar installer and SMUD were able to source many of the components locally, thereby avoiding shipping costs.
- There were no extra components on this job. The availability of a quick connect crimper on site allowed the final crimping to the exact wire length needed.

Protective Coating

- The protective coating was too wide, covering more than the active area of the laminate. It had to be peeled back before the battens were applied resulting in extra installation time. The active area of the laminate is approx. 13 ¼ inches wide, the protective coating is 14.5 inches wide. The problem could be resolved by eliminating 1 inch from the width of the protective coating.
- The protective coating did not appear to be rolled onto the laminate and came off when the laminates were rolled out on the roof. When the protective coating was

rolled onto the laminate it provided a superior surface to walk on and limited the possibility of damage to the laminates.

Revised Design of Clamping Batten System

This field trial was the first to use insert molding and established these new battens as a superior system in both cost and time needed to complete the installation.

Packaging and Shipping of Batten, Trim and Flashing Kit

A significant reduction in shipping cost was achieved by shipping the trim and flashing kit by common carrier directly from the manufacturer rather than delivering it to the site from Uni-Solar. The battens were brought to the site in two small shipping tubes on top of a car. The laminates were shipped in one large box which required a forklift to deliver, instead of the small boxes that were requested.

Cost Analysis

Travel expenses incurred on this project were significantly less than previous field trials because a trained local installer was used. A cost analysis of the 1,914 Watt PVR system is as follows:

Table 3. Breakdown of installed cost for Field Trial No. 4

System Size = 1914 Watts				
Materials	\$ T	otal	\$ / Watt	
PV Laminates	\$ 7,7	798 \$	4.07	
Inverter	\$ 1,3	378 \$	0.72	
Balance of System	\$ 1	38 \$	0.07	
Metal Flashing	\$ 1	67 \$	0.09	
Insert Molding	\$ 4	169 \$	0.25	
Butyl tape	\$	50 \$	0.03	
Miscellaneous parts	\$	24 \$	0.01	
Installation contract	\$ 3,8	307 \$	1.9 <u>9</u>	
Total Installed Cost	\$ 13,8	331 \$	7.23	

Data collected by Steve Heckeroth

The greatest cost reduction came from the lower cost for batten and trim kit. At \$0.38 a Watt, it was a fraction of cost of the batten and trim in previous field trials.

SMUD Hedge Substation, sacramento installation photos



Figure 36. Chalk lines on VersaShield underlayment

Photo Credit: Uni-Solar



Figure 37. The first two laminates in place



Figure 38. Bonding laminates to roof deck



Figure 39. All laminates in place



Figure 40. Protective coating removed, ready for ridge cap Photo Credit: Uni-Solar



Figure 41. Combiner box and inverter wiring



Figure 42. The completed roof

Fourth Field Trial Conclusions

Using a local installer and the improved insert molding Clamping Battens System significantly lowered the overall cost of this field trial. The installation shows no signs of deterioration or weathering a year after the installation was completed.

Fifth Field Trial Conclusions

Installation on a residential roof was performed by a local PV installer using the improved insert molding Clamping Battens System. The result was a very attractive low-profile PV Roof which blends well with the composite shingle roof.



Figure 43. PVR roof on Orangevale residence
Photo Credit: Uni-Solar

3.6 Equipment Design

3.6.1 Design Documents for Equipment to Produce Shipping and Installation Tools

To improve the manner in which the laminates were protected during shipping and installation, Uni-Solar implemented the use of 5 mil, 14.5-inch wide opaque protective covering. This keeps the laminates clean and prevents damage during shipping and installation while providing protection from electric shock during installation. This was a great improvement over the paper held together with masking tape that was originally used for this purpose.

The design work for the shipping spool and ridge/eave roller was completed and detailed in Sections 3.1.1 and 3.1.2. These can allow the release of the laminates from the shipping spool as the ridge/eave roller is moved along the ridge of the roof to simplify the installation process and reduce costs. After a thorough discussion and review of the designs created, it was determined that no specialized equipment is needed to produce the shipping and installation tools. Any job shop with standard equipment and tools can manufacture them. Uni-Solar has no plans to source these components at this time. The PVL products are now packaged rolled up in cardboard boxes. This is a satisfactory method for shipping, as it only requires a mechanical pallet jack to load or move.

The use of quick connects instead of junction boxes, which had to be glued to the laminate, then connected with conduit and then wired by expensive electrician labor

reduces the installation time and therefore cost. The quick connects can be plugged together in seconds. Integrating the quick connects into the assembly line has been accomplished.

The protective coating and the jig to trim laminates have also been incorporated into the production of the laminates. The new widths required of later revision PVR are relatively simple to manipulate.

3.6.2 Design Documents for Equipment to Produce the Clamping Batten System

The Design Rev. 3 Insert Molding Clamping Batten System shown in Figure 16 makes use of off-the-shelf commercially available components. The following sources have been identified for each of the three components that make up this PVR System:

Double-stick butyl tape:

Sika Corporation

14201 Botts Road.

Grand View, Mo 64030

Phone: 816-316-4200

• Insert molding and screw cover:

All-Rite California

1500 Shelton Drive

Hollister, CA 95023

Toll Free: 800-642-9988

International: 831-636-9566

All-Rite Georgia

2580 Jeremiah Ind. Way

Conyers, GA 30012

www.All-Rite.com

After a thorough discussion and review of the designs created, it was determined that no specialized equipment was needed to produce the clamping batten system since these components were commercially available.

4.0 Conclusions and Recommendations

As a result of this project, United Solar Ovonics has developed a commercially viable photovoltaic roofing product that can be installed on virtually any roofing sub-structure. The installation is simple, fast, and provides a low profile end-product that is aesthetically superior to other PV systems. Furthermore, the large area laminates can be used as a roofing material, entirely avoiding the necessity of roofing underneath conventional rack-mounted PV modules.

4.1 Conclusions

The result of this project is a commercially viable photovoltaic roofing solution that is inexpensive and installs quickly and easily. It can be applied to almost any type of roof—new or existing.

Benefits of the PV Roof include increased customer acceptance, lower cost, and easy installation with optimum aesthetics. The PV Roof will blend in with the surrounding roof and add to, rather than detract from, the overall appearance of the building. The PVR product provides several innovative benefits that will help to reduce the cost of PV for residential buildings, including:

- Reduced installed prices for a UL listed PV Roofing system to \$7 to \$8/Watt.
- Increased customer acceptance due to improved aesthetics.
- Improved access to electrical termination with ridge cap strategy.
- Eliminated roof penetrations.
- Allowed application on odd shaped roofs due to different length laminates.
- Achieved fast and easy installation (128 Watt module in less than 10 minutes).

4.2 Commercialization Potential

The Uni-Solar PVR product has a distinct advantage over other BIPV products. Besides being inexpensive compared to other PV products, Uni-Solar's PVR is market ready, UL listed, and has a manufacturing capacity of 30 MW behind it. Because it requires the fewest interconnections, it can be installed faster and easier than any other available BIPV products. This, combined with its superior aesthetics, makes it a very competitive product.

Uni-Solar's PVR is ideally suited for integration with buildings. United Solar has already made alliances with several master roofing contractors and manufacturers of roofing materials around the world to integrate its products with roofs for commercial buildings. For example, Solar Integrated Technologies, a California company, has agreed to buy substantial quantities (more than 5 MW in 2004) of Uni-Solar products to be incorporated in single-ply membranes for commercial buildings.

The residential market also offers tremendous opportunities. California continues to be in a building boom, adding about 186,000 new homes a year. The State needs 230,000 new homes to keep up with population growth. The building rate is expected to increase in the next several years.

California has experienced significant increases in energy prices in the past three years, with rolling blackouts not too distant in people's memories. California customers are aware and interested in the benefits of PV. To satisfy the demand, developers in California are seeking new products to differentiate their offerings from their competitors. This has created an unparalleled market for building integrated PV (BIPV).

Uni-Solar has already invested more than \$60 million to set up a state-of-art production plant with 30 MW annual production capacity and, once the company turns its attention to domestic residential and commercial market, stands poised to capture a significant market share.

4.3 Recommendations

The product development goals of this project have been accomplished, resulting in a superior BIPV product. It is now important to obtain a larger market share for this product. The current residential BIPV program of Uni-Solar relies on direct sale to the homeowner. Although this approach has achieved limited success in San Diego, it is critical that alliances are made with homebuilders in order to have a national outreach. The two trades, PV and roofing, are quite different, and for the alliance to be successful it is necessary to form dedicated teams in both industries that can speak the same language. Training of the roofing personnel to install PV products is critical to grow the market.

To increase the marketability of this product, more data should be generated in different geographic locations in United States to verify and inform customers that amorphous silicon-based products produce more kWh/kW than conventional crystalline silicon PV. This is a unique selling point of Uni-Solar products. Confirmation of such results by well-known independent agencies in the United States will enhance market acceptance.

4.4 Benefits to California

California is one of the most likely candidates for these systems due to its almost continuous sunshine, growing need for energy, and its environmentally aware citizens who desire to expand solar energy usage in the state. Uni-Solar's PV systems are silent, pollution free and, with the advancements made from this project, attractive and inexpensive to install. Widespread deployment of these PV systems on new homes and buildings would benefit California with reduced pollution, increased energy security due to a reduced need to import energy, and reduced peak demand for grid-supplied electricity, therefore mitigating the need to build new power plants and reducing the likelihood of system shortages. To see these results, PV must first be widely accepted and deployed in the state.

Unrivaled in terms of low cost and ease of installation, the PVR product developed under this project could be the most competitive BIPV marketed to date. As such, it is a strong contender to be widely accepted in homes and buildings throughout the state.

Glossary

AC Alternating Current. An electric current that reverses direction (sine wave). In the U.S., most household current is single-phase AC at 60 cycles per second. Many businesses in the U.S. that have larger electrical needs use 3phase AC at 60 cycles per second. Sometimes abbreviated as "a-Si," amorphous Amorphous Silicon silicon is a disordered semiconductor material deposited in a plasma-enhanced chemical vapor deposition (PECVD) process to create thin-film solar cells on a substrate. Amps The unit of electrical current. Can be thought of as the "flow rate" of electricity. A group of modules wired together (in a series Array (photovoltaic) and/or in parallel) to form an array of solar modules. BIPV Building-integrated photovoltaics BOS or Balance of System (photovoltaic) The parts of a photovoltaic system other than the array. For instance: switches, controls, meters, power conditioning equipment. supporting structure for the array, storage components, etc. Cell (photovoltaic) The smallest unit of a solar module. A typical a-Si solar cell is rated at 1.5 volts. A typical crystalline solar cell is rated at 0.5 volts. Components Refers to other devices used and needed when building a solar system. Having a repeating atomic structure in all three Crystalline dimensions. DC Direct Current. An electric current flowing in one direction only. Grid-Connected (photovoltaic) A photovoltaic system in which the PV array supplies power directly to a load center (i.e. AC Service Panel) in a home or commercial facility. There is no on-site storage device included with a grid-connected photovoltaic system. Instead, all the kilowatt-hours generated by the PV system are either used by the loads connected to the load center in the building or they are pulled into the utility grid power lines via the utility kilowatt-hour meter attached to the building. Inverter An Electronic Device that changes direct current (DC) to alternating current (AC). Kilowatt 1000 watts; an incandecent light bulb uses 40 to 100 watts. 1.000.000 watts. Megawatt Module (photovoltaic) PV modules are manufactured and assembled using solar cells, interconnect wire, bypass diodes, encapsulant (which is a top cover over

the solar cells) and a protective back sheet behind the solar cells. Most solar modules also include a frame around the edges of the back Peak Power

Photovoltaic (PV)

PV PVL PVR

Photovoltaic Cell

Roll-to-Roll Process

Series Connection

Solar

Solar Collectors

Solar Panel

Systems; Balance of Systems

Thin Film

UL Volts

Voltage Watts sheet/top cover assembly. Together, all of these components form the solar PV module. Maximum power rating for some particular device.

Direct conversion of light into electrical energy.

Photovoltaic.

Site-bonded photovoltaic laminate.

Building integrated photovoltaic roofing system. The treated semiconductor material that converts solar irradiance to electricity.

A process where a roll of substrate is continuously converted into a roll of product.

Connection in which the current (amps) stays

the same but the voltage multiplies.

Energy from the sun.

A device designed to capture light or heat energy from the sun. Solar thermal collectors are used in solar hot water systems (often found in homes) and photovoltaic collectors are used in solar electric systems.

Another name for a single module or a group of solar modules that are part of a solar electric PV system.

Solar electric systems include the photovoltaic array and the other components that allow these solar panels to be used in homes and commercial facilities where a regulated DC power supply or an AC power supply is required. Components used in solar electric systems include; wire and disconnect devices, charge regulators, inverters, metering, and grounding components.

A very thin layer of material formed on a substrate.

Underwriters Laboratories Inc.

The unit of electromotive force that will force a current of one amp through a resistor or one ohm.

The measurement of the force of electricity. A measure of electrical power that is determined by multiplying the voltage by the amperage.